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LEMNA MINOR AS AN AGGRESSIVE WEED IN THE SUDBURY RIVER

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For the past ten years a remarkable development of *Lemna minor* in the late summer and early autumn has become a conspicuous and rather disconcerting feature of the Sudbury River in eastern Massachusetts. During periods of peak abundance, as in mid-September, 1936, when I first noticed it, the entire river surface, except around sharp bends and in the narrows where the flow is accelerated, is for many miles literally choked with the floating plants, slowly moving down stream with the current. After copious rains or during prolonged southwesterly winds the Lemna stretches out in long ribbons or streamers, presumably due to the increased rate of flow. As would be expected, the abnormal abundance of the plant—now an annual phenomenon since 1936—varies from week to week and year to year. Short-term fluctuations appear to be related to changes in water temperature, wind and speed of the current. The stream is normally so sluggish in August and September that the rate of vegetative reproduction of the plants in mid-stream far exceeds the capacity of the river to drain them away.

It seems to be reasonably certain that we are discussing a recent phenomenon, the like of which had never before been observed for at least a hundred years. The appearance of the Lemna in 1936 caused a great deal of comment on the part of many people. Keen observers of the older generation, familiar with the river at all seasons from childhood, were quick to say they had never seen anything like it previously. I find no allusions to any unusual or conspicuous development of Lemna or "green scum" on the river in Thoreau's or Brewster's journals. Surely each of them would have commented on it had they been alive during the present decade.

Curiously enough, a similar invasion of *Lemna minor* was noted in the Charles River (eastern Massachusetts) in 1937 and probably occurred in 1936. Mr. F. W. Hunnewell stated in correspondence (September 16, 1937) that the Charles River had been green with something all summer which, on closer examination, proved to be solid *Lemna minor*. He also referred to friends who live beside the river in Dover and who had been "talking about the unusual 'green scum' for the last couple of years". Mr. S. N. F. Sanford, in a letter of October 11, 1937, enclosed a clipping from an unidentified Boston newspaper published early in September, 1937, under the caption, "Millions of Small Plants Cover Charles". The opening sentence reported, "millions of tiny plants, resembling shamrocks in color and appearance, turned the surface of five miles of the Auburndale section of the Charles River into bright green yesterday . . ." Mr. Sanford visited the Norumbega Park section on September 26, 1937, and found a quantity of *Lemna minor* along both sides of the stream sufficient to attract attention. Mr. Edward Wright of the Massachusetts State Department of Health recently told me that there had been much complaint on the part of patrons of the public bathing places on the river at Dedham late last summer because of the great quantities of a small green plant floating on the water.

The sudden and unprecedented appearance of vast quantities of Lemna at approximately the same time in two unconnected rivers early in September, 1936, and again in 1937 suggested at the time that a somewhat ephemeral "explosion" of the species had occurred due to some extremely unusual combination of favorable factors. To check such a possibility, I examined the excellent daily meteorological records accumulated by Mr. F. A. Tower of Concord for many years. Analysis of daily, weekly and monthly maximum and minimum air temperatures gave no hint of abnormality in 1936 or 1937. Nor was the wind velocity or direction unusual for any period of time. Rainfall data were equally disappointing. There remained the question of significant variations of soluble nutrients in the water—a question which was pigeon-holed for ten years.

The continued unusual abundance of Lemna in the Sudbury River up until the present time suggested the possibility of a definite change in ecological conditions in the river beginning in the mid-thirties. Lacking the facilities to make a thorough study of this question, I have examined the incomplete water analysis records of the Massachusetts State Board of Health to find a clue to the mystery.

Samples of Sudbury River water taken regularly for many years at several stations between its source and confluence with the Assabet have been analyzed by the State Board of Health. The records are not wholly satisfactory. Those prior to 1900 have been mislaid or lost. The reports for the years 1905–1907 are missing. Although nitrogen in the form of free and albuminoid ammonia is recorded for each sample analyzed, the data for soluble nitrates were unrecorded for the period 1916–1934. The yearly averages given in Table I are derived from analyses of samples taken at reasonably regular intervals varying from 12 to 3 times per year. From 1903 through 1944 six samplings per year between June and November was the general but not invariable practice; in 1945 the number was reduced to four (July, August, October, November). Obviously, such infrequent analyses will show misleading variations in the apparent amount of pollution. Assuming a constant volume of pollution, the analyses during a wet season will differ from those of a dry season; likewise, a sampling after a heavy summer rain may show less pollution than one taken at a low water stage of the river preceding the rain. In the table below, to minimize the chance distortions of the data, the analyses of each sampling have been averaged for each year; and for soluble nitrates these averages in turn combined into three-year averages to show trends. In Table I are shown the yearly and three-year averages for free plus albuminoid ammonia, and the soluble nitrates, all expressed in parts per one million.

That the Sudbury River has become increasingly polluted since 1900 is evident. As measured by the total free plus albuminoid ammonia content of the water, the pollution tide ebbed and

WATER ANALYSIS

Table I.—Free and Albuminoid Ammonia
(parts per 1,000,000)

	Sudbury River at Concord					Charles River at Needham				
	Ammonia			Nitrates		Ammonia			Nitrates	
	Free	Total	3 Yr. Av.		3 Yr. Av.	Free	Total	3-Yr. Av.		3-Yr. Av.
1900	.030	.271		.001		—	—			
1901	.056	.371		.089		—	—		—	
1902	.067	.336	.326	.088	.059	—	—		—	
1903	.050	.329		.057		—	—		—	
1904	.052	.373	.351	.058	.052	—	—		—	
1905	—	—		—		—	—		—	
1906	—	—		—		—	—		—	
1907	—	—	—	—		—	—		—	
1908	.049	.268		.023		—	—		—	
1909	.052	.312		.018		—	—		—	
1910	.052	.298	.293	.028	.023	—	—		—	
1911	.036	.280		.022		—	—		—	
1912	.052	.338		.023		—	—		—	
1913	.166	.495	.371	.083	.043	—	—		—	
1914	.133	.423		.072		.058	.358		.062	
1915	.137	.543		.060	.066	.064	.449		—	
1916	.123	.407	.458	—		.059	.330	.379	—	—
1917	.122	.471		—		.055	.360		—	
1918	.086	.420		—		.088	.441		—	
1919	.111	.452	.448	—		.089	.409	.403	—	—
1920	.125	.333		—		.062	.289		—	
1921	.127	.372		—		.048	.333		—	
1922	.111	.346	.350	—		.043	.238	.287	—	—
1923	.113	.318		—		.072	.294		—	
1924	.101	.286		—		.082	.296		—	
1925	.143	.402	.335	—		.108	.400	.330	—	—
1926	.096	.397		—		.084	.417		—	
1927	.163	.529		—		.069	.458		—	
1928	.113	.394	.440	—		.076	.405	.327	—	—
1929	.106	.326		—		.067	.283		—	
1930	.191	.379		—		.221	.436		—	
1931	.213	.447	.384	—		.121	.397	.372	—	—
1932	.116	.358		—		.069	.288		—	
1933	.257	.532		—		.140	.417		.118	
1934	.177	.432	.441	—		.246	.524	.410	.083	.101
1935	.196	.466		.190		.167	.563		.103	
1936	.243	.501		.340		.198	.679		.210	
1937	.178	.490	.486	.120	.217	.035	.398	.547	.200	.171
1938	.311	.640		.160		.094	.475		.270	
1939	.106	.446		.230		.023	.366		.130	
1940	.096	.502	.529	.200	.197	.040	.352	.398	.120	.173
1941	.076	.488		.250		.072	.412		.130	
1942	.311	1.296		.340		.115	.570		.170	
1943	.135	.442	.742	.170	.253	.145	.445	.476	.270	.190
1944	.206	.513		.220		.096	.461		.326	
1945	.130	.382		.480		.102	.423		.260	
1946	.047	.389	.428	.130	.277	.059	.248	.377	.175	.254

flowed from year to year, but increased each successive nine-year period. By far the greatest increase occurred in the period 1935–1943, from .421 to .586, or 39%. However, the increase was gradual until 1938. No obvious correlation exists between these data and the sudden mass invasion of Lemna in 1936.

Theoretically, the increase of the free ammonia component of the water might be significant. According to M. L. Fernald, "*Lemna minor* usually does not occur in acid or bog waters but in the sub-neutral to basic or slightly alkaline waters which sewage, etc., supply." (1) From 1900 to 1912 free ammonia varied between .030 (1900) and .067 (1902), the average for the period being .0496. From 1913 through 1929 the variation was from .086 (1918) to .166 (1913) and the seventeen year average, .122. In 1930 free ammonia at .191 was higher than in any previous year; and the average for the period 1930–1946 was .176. However, a glance at Table I will show an extremely wide variation (.213 in 1931, .116 in 1932, .243 in 1936, .311 in 1938, .106 in 1939, .076 in 1941, etc.) with no discernible pattern of change. Here, again, the data fail to give any hint as to what trigger action set off the alleged Lemna explosion in 1936.

As measured by the soluble nitrate analyses, the increase in the more readily available plant nutrients is striking. It is an exasperating "rub of the green" that the data are lacking for precisely those years when they are the most significant. The yearly, three- and nine-year averages show a relatively stable low-level nitrate component from 1900 through 1915, after which year no figures for nitrates were compiled until 1935. In that year, the average was 3.1 times the 1915 level; and the 1935–1937 average was 3.0 times the 1913–1915 average. The lowest three-year average of data from 1935 to 1946 is three times as great as the highest three-year average during 1900 to 1915.

An inspection of similar records of analyses of Charles River water sampled at Needham reveals a similar pollution pattern. The records begin with the year 1914, there being a gap in the data for soluble nitrates from 1915–1932. The average of nitrates for 1914 was .062, as compared with .072 for the Sudbury in the same year. The three-year average, 1933–1935, was .101. The average for 1936 was .210, about twice the amount recorded in 1935, and more than three and a half times the amount recorded for 1914. From 1936 on, the three-year averages varied from a high of .255 to a low of .127. The 1936–1946 average was .206. The trend of ammonia pollution was comparable to conditions in the Sudbury, and apparently uncorrelated with the Lemna invasion.

Thus, there is a possible correlation between the increase of Lemna and the increase of river pollution, particularly in the form of soluble nitrates. It is assumed that a combination of factors has created optimum ecological conditions for the development of Lemna in the two rivers beginning in the mid-thirties. It is possible that the naturally acid water of these streams may have finally become sub-neutral or slightly alkaline as a result of the gradual increase of free ammonia, thus providing ideal conditions for rapid development of Lemna when copious supplies of nutrients became available. Doubtless there are other factors at work which some inquisitive ecologist may be tempted to investigate. A series of controlled experiments in the propagation of *Lemna minor* under varying conditions might yield interesting results. In fact, the effect of water pollution on aquatic vegetation deserves far more intensive study than has as yet been devoted to the subject, not only in the interest of pure science, but to give aid and comfort to the economic biologist on whom the population of the world will be increasingly dependent during the century to come.

The question naturally arises whether Lemna is peculiarly responsive to the increase of pollution which is tentatively proposed as responsible for its aggressive behavior. What about other aquatics? Although I lack any precise data on the subject, there seem to have been marked vegetational changes in the Sudbury River during the past fifteen years. *Trapa natans* was introduced from Europe in the river a great many years ago. There is a specimen in the Herbarium of the New England Botanical Club from Concord dated August 29, 1859. In the course of time it became generally distributed along many miles of the river and in certain favorable back waters formed dense mats a rod or two in diameter. On the whole, however, it remained relatively unaggressive and well behaved until recently. Last summer I noticed that it had taken complete possession of long stretches of the river-margin from Fairhaven Bay to Concord Village and beyond, where ten years ago the native vegetation was predominant. In contrast, I became acutely conscious of the scarcity of *Nymphaea odorata*, formerly a conspicuous and abundant feature of the river, but now rapidly fading out even in places not yet invaded by Trapa.

Impressions are misleading, but in this case are so striking that they immediately renewed my interest in the ten-year-old Lemna problem. I asked Dr. H. B. Bigelow, who has lived beside the river for many years, if he could confirm my feeling about the recent scarcity of Nymphaea. He writes (2), ". . . it is certainly a fact that the water lilies have been very much reduced in number since the Lemna came." He also discussed "the still more spectacular explosion of the . . . water chestnut (*Trapa natans*) that took place in our part of the river summer before last and which continued during this past summer . . . All the years I have lived there (on the bank of the Sudbury River), there have been a few of them scattered among the water lilies, etc. Summer before last the thing ran wild and last summer it so multiplied in our stretch that no water at all was to be seen, except along the thread of the stream. In fact, the shallow parts looked like dry land and it was difficult to shove a canoe through it." Here is comforting corroboration of my own impressions from a competent naturalist and trained observer.

It is noteworthy that *Nymphaea odorata* occurs chiefly in neutral to slightly acid water overlying rich organic muds, whereas Trapa in its native habitat, according to Hegi, is found in "weakly calcareous but rich warm muds". (3) As for the Lemnaceae, Fassett states that "the genera . . . occur in hard water". (4)

These facts tend to support the hypothesis that alkaline sewage wastes have an important bearing on the weedy behavior of *Lemna minor* in Sudbury and Charles Rivers.

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